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AUTOMATED PARTIAL-DISCHARGE TESTING OF TRAVELING-WAVE TUBES,(U)
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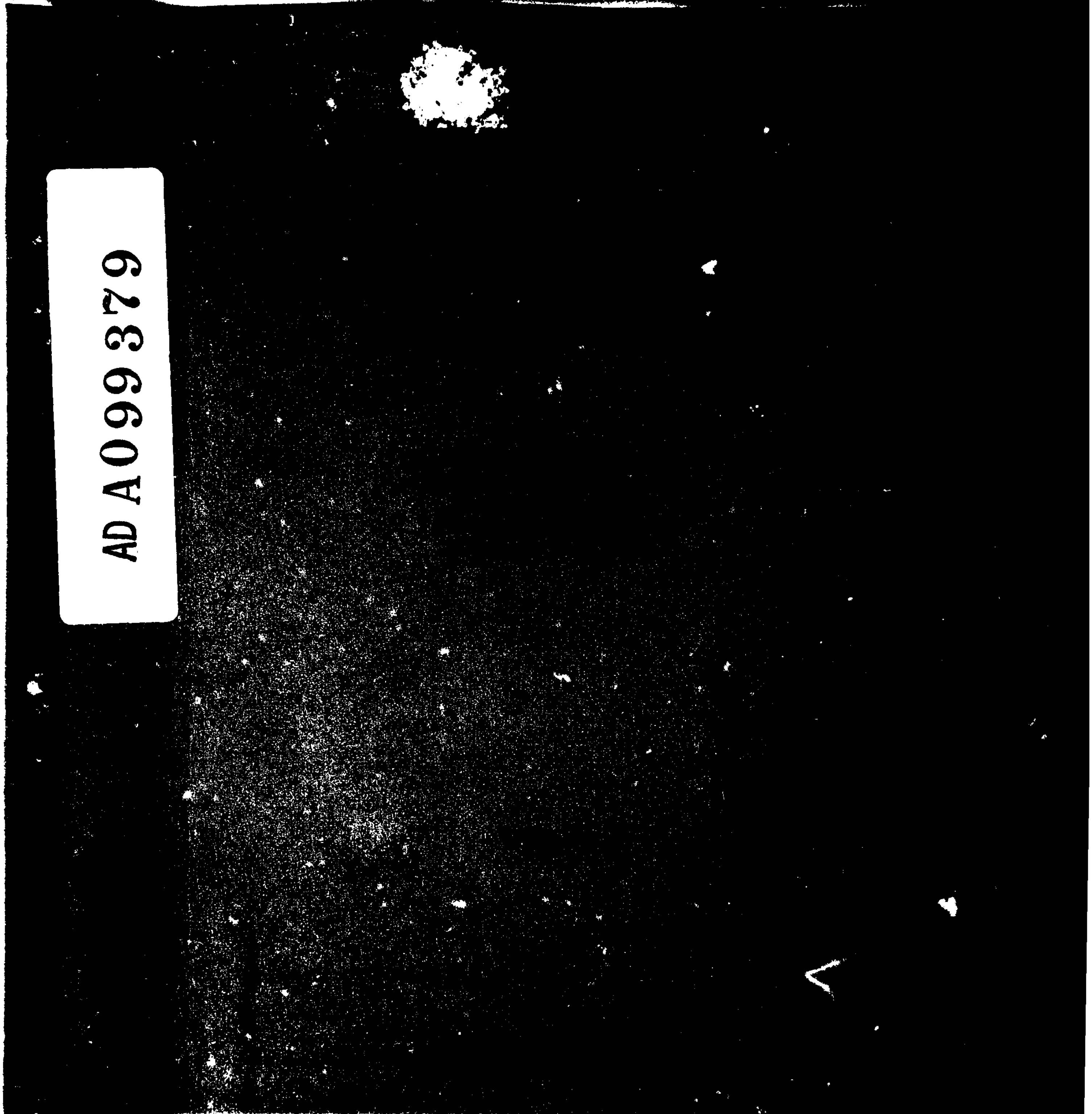

Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

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John A. Criscuolo
John A. Criscuolo, Major, USAF
Project Officer

Florian P. Meinhardt
Florian P. Meinhardt, Lt Col, USAF
Director of Advanced Space Development

FOR THE COMMANDER

William Goldberg
William Goldberg, Colonel, USAF
Deputy for Technology

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

A test system is described that is used in the Materials Sciences Laboratory to evaluate the quality of high-voltage insulation in traveling-wave tubes (TWTs). Evaluation is performed by quantitatively recording the occurrence of partial discharges during temperature cycling in vacuum for extended periods.

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CONTENTS

FIGURES

I. INTRODUCTION

One of the most useful techniques for detecting flaws in high-voltage insulation is to apply a voltage and then record the frequency and amplitude of any partial discharges that may occur. The methods used for making this type of measurement are well known.[1-3] To achieve maximum usefulness from the partial-discharge testing technique, it is necessary to take measurements for extended periods of time while cycling the temperature of the insulation that is being tested. The Materials Sciences Laboratory has assembled test systems to make this type of measurement and to carry out the computerized collection of data.

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[1] F. Hai and K. W. Paschen, Development of a Partial Discharge Detection System for Traveling Wave Tube Testing, TR-0079(4402)-3, The Aerospace Corporation, El Segundo, Calif. (28 September 1979).

[2] IEEE Std. 454-1973, IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.

[3] ASTM D 1868-73, Standard Method for Detection and Measurement of Discharge (Corona) Pulses in Evaluation of Insulation Systems.

II. PARTIAL-DISCHARGE DETECTION

Partial discharges from a TWT are detected by applying a negative voltage to either the collector or cathode lead and then measuring any electrical activity at the other electrodes, those that are separated from the collector or cathode by ceramic insulators or potting material. The detection system consists of the following subsystems:

1. An input circuit consisting of a high-voltage power supply and charge sensing circuit, usually an inductance, together with a calibration signal generator.

2. A preamplifier to amplify the signal from the charge sensing circuit.

3. A pulse amplitude discriminator to divide the signal into several channels, each representing a range of charge magnitude.

4. Counters and a timer to count the number of discharges in each channel during a specified time period.

5. An automation system to control the acquisition of partial-discharge data and provide periodic printout of counts in each channel along with the time, temperature, and voltage during each counting period.

A. INPUT CIRCUIT

Figure 1 is a schematic diagram of the input circuit used on the partial-discharge test system. Voltage is obtained from a high-voltage, dc, filtered power supply, which is further filtered by the RC network R1-C_{cc}. The noise-free high voltage is applied to the test sample C_t, which is in a vacuum chamber to simulate a space environment. The signal generator with C_c is used to calibrate the system in units of charge. A step-function pulse of amplitude V_c is injected through C_c to calibrate at charge level V_cC_c. The resistor R3 limits surge current in case sample C_t shorts out or sparks over. The inductance L1 forms a resonant tank circuit that oscillates when a partial discharge occurs. The amplitude of the oscillation is proportional to the charge transferred by the partial discharge. This damped oscillation is inductively coupled to the preamplifier by a small coil of wire wrapped around L1. L1 consists of No. 30 Teflon-insulated wire wound on a Lucite cylinder 2.25 in.

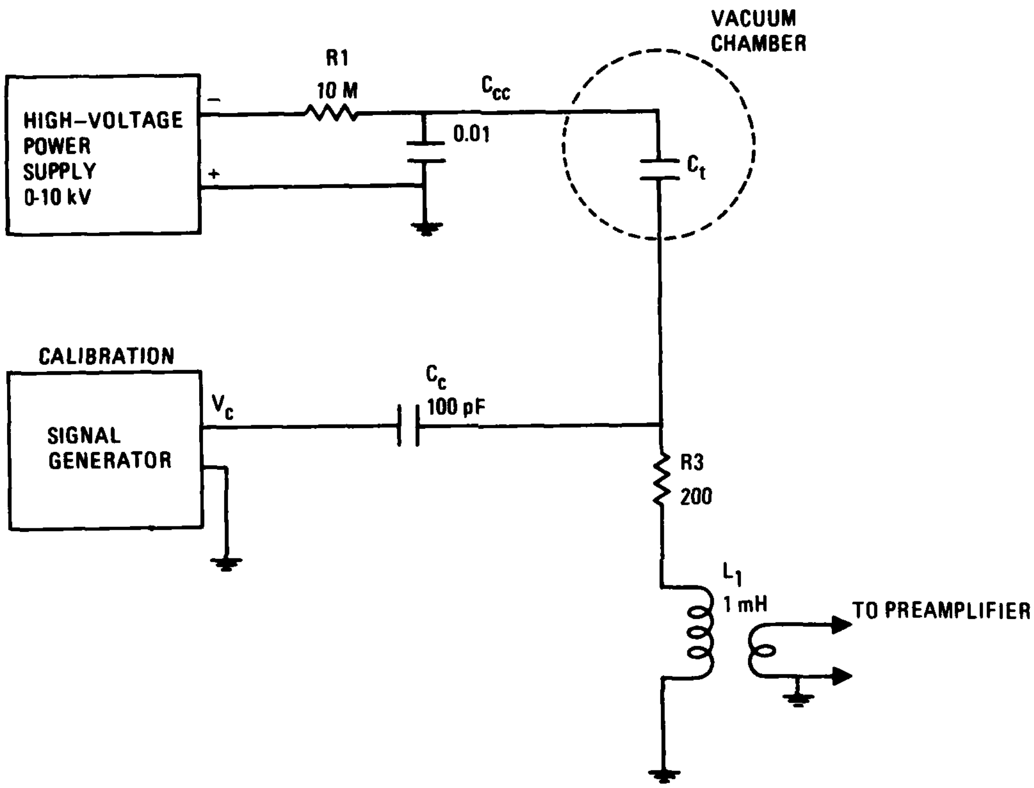


Fig. 1. Input Circuit

in diameter and 5 in. long. This large wire is used to prevent burnout when C_t sparks over or shorts out. An oil-filled capacitor rated at 14 kV was used for C_c for the same reason.

B. PREAMPLIFIER

Figure 2 is a schematic diagram of the preamplifier. It is designed to cover a large dynamic range and incorporates a four-decade-gain switch, S1. The input coil L2 is a conventional 1-mH radio frequency choke with an additional few turns wrapped to inductively couple the input signal to the preamplifier. Inductive coupling is used to minimize noise pickup resulting from ground loops. The capacitor C_2 (actually an array of capacitors with switching to cover a broad range of capacity) is used to resonate L2 to the same frequency as L1 in the input circuit. It is simply adjusted for maximum amplitude when the calibration pulse is applied. The rest of the circuit is a conventional solid-state amplifier with low impedance output for driving a long coaxial cable.

C. CALIBRATION SIGNAL GENERATOR

The partial-discharge test system is calibrated by means of a signal generator (Fig. 3). This generates a step function with amplitude V_c followed by a slow decay to zero level. The step function can be initiated manually or can be repetitively generated by a periodic input pulse. The amplitude of the generator output V_g is adjusted to the maximum charge level with the aid of a calibrated oscilloscope. A four-decade attenuator switch is used to reduce V_g to convenient levels of calibration voltage V_c.

Q1	---	2N2222	C2	---	11 TO 2000 pF	R4	---	7.5 k	R14	---	6.2 k
Q2	---	TIP 33A	C3	---	8 pF	R5	---	0–5 k	R15	---	1 M
L2, L3	---	lmH	C4, C5	---	1 pF	R6	---	8.2 k	R16	---	2.2 k
D1, D2	---	HEP 170	C6, C7, C8, C9, C11	---	0.1 MFD	R7	---	2.2 M	R17	---	1 k TRIM-POT
			C10	---	56 MFD	R8	---	160 k	R18	---	24 k
			C12	---	1000 MFD	R9	---	5 k TRIM-POT	R19	---	150 2 W
						R10	---	680	R20	---	57
						R11	---	560 k	R21	---	10 k
						R12	---	2.2 M			
						R13	---	0–250			

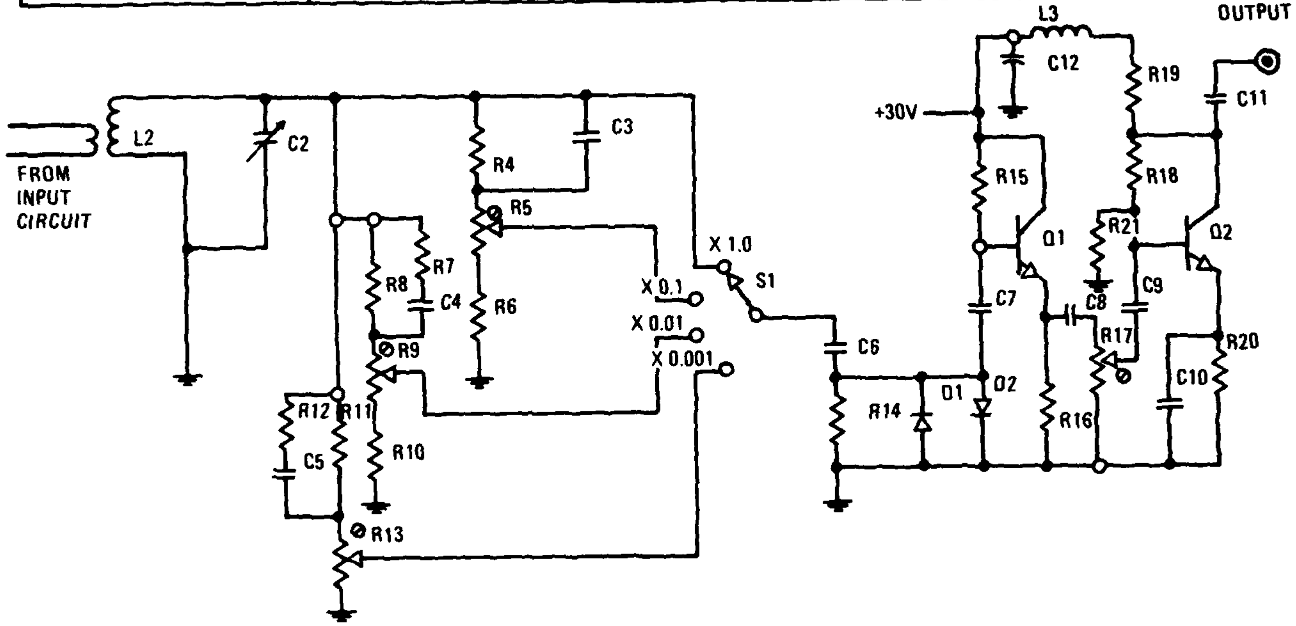


Fig. 2. Preamplifier

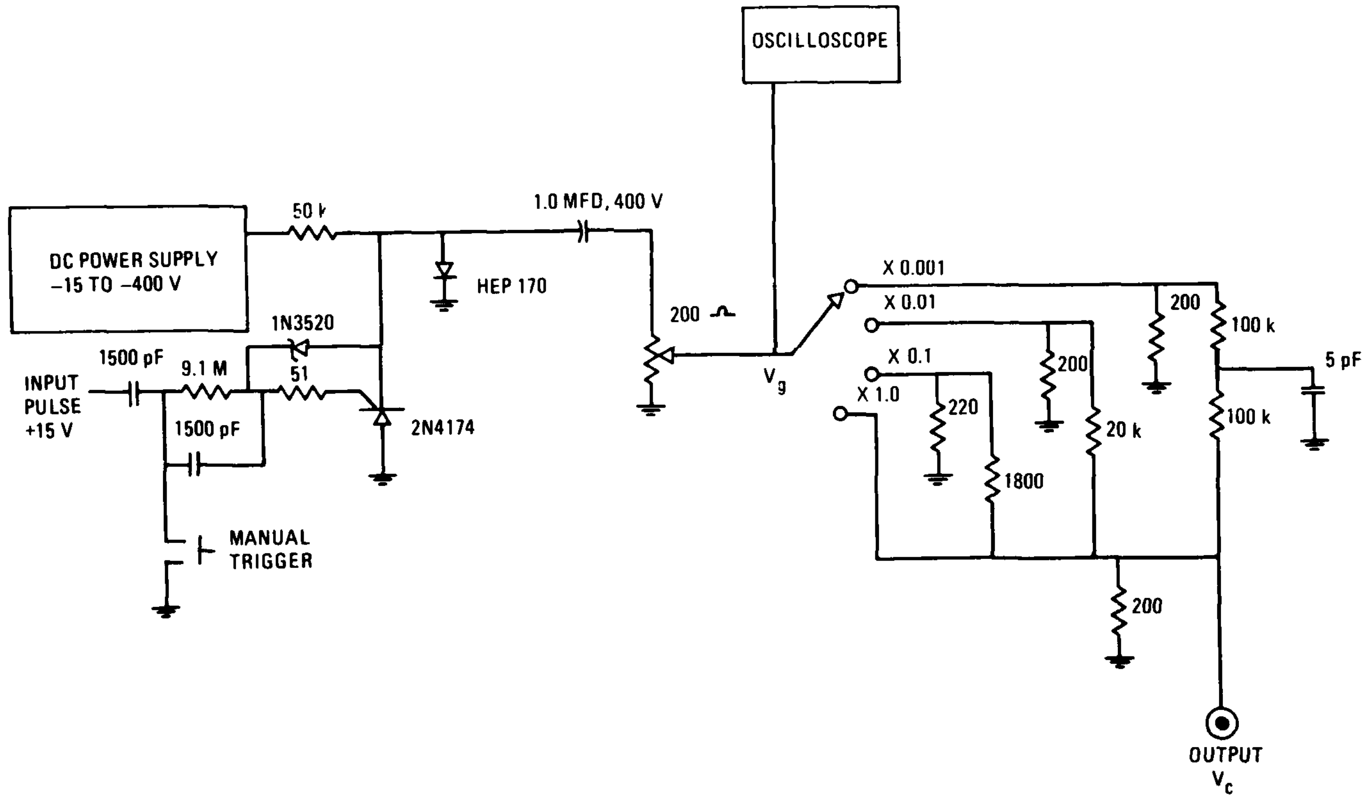


Fig. 3. Calibration Signal Generator

III. AUTOMATION OF PARTIAL-DISCHARGE TESTS

The input circuit and preamplifier are the means by which partial-discharge pulses are detected and amplified from a dielectric sample. After being detected by the preamplifier, the pulses are sorted in four amplitude groups and counted for a finite time period. The system is automated by tabulating, storing, and printing the counts as hard copy under computer control. Other important parameters are also printed out along with the count data for each amplitude group. These include time, sample temperature, voltage applied to the sample, and pressure in the vacuum chamber.

Two data-processing systems can be used. For the first system a MOS technology KIM-1 microcomputer is used to control the process, while for the second, a Hewlett Packard type 9835A desktop computer is used. The input circuit and preamplifier previously described are used for both systems.

A. KIM-1 SYSTEM

Figure 4 is a block diagram of the KIM-1 test system. The signal, from the preamplifier, is further amplified and then divided into four amplitude groups by the pulse amplitude discriminator shown schematically in Fig. 5. A tunable filter, R1-L1-C1, is used to increase the signal-to-noise ratio of the pulse input. C1 is adjusted for maximum signal amplitude when the calibration pulse is applied at the input circuit. From the filter, the signal is fed in parallel to four attenuators (controlled by R4, R8, R11, and R14). After passing each attenuator, the signal is amplified, and then triggers a one-shot multivibrator IC1. This results in four outputs, each triggered by a different amplitude as determined by the settings of the attenuator controls. The one-shot multivibrator period is 0.5 msec to prevent multiple counting of single discharges. This sets an upper limit to count rate, but this limitation is normally not a problem.

The four discriminator outputs are fed to the input-output port of the KIM-1 computer, where each channel is counted for a period determined by the timer and stored in memory. A count display, consisting of four scalers, is

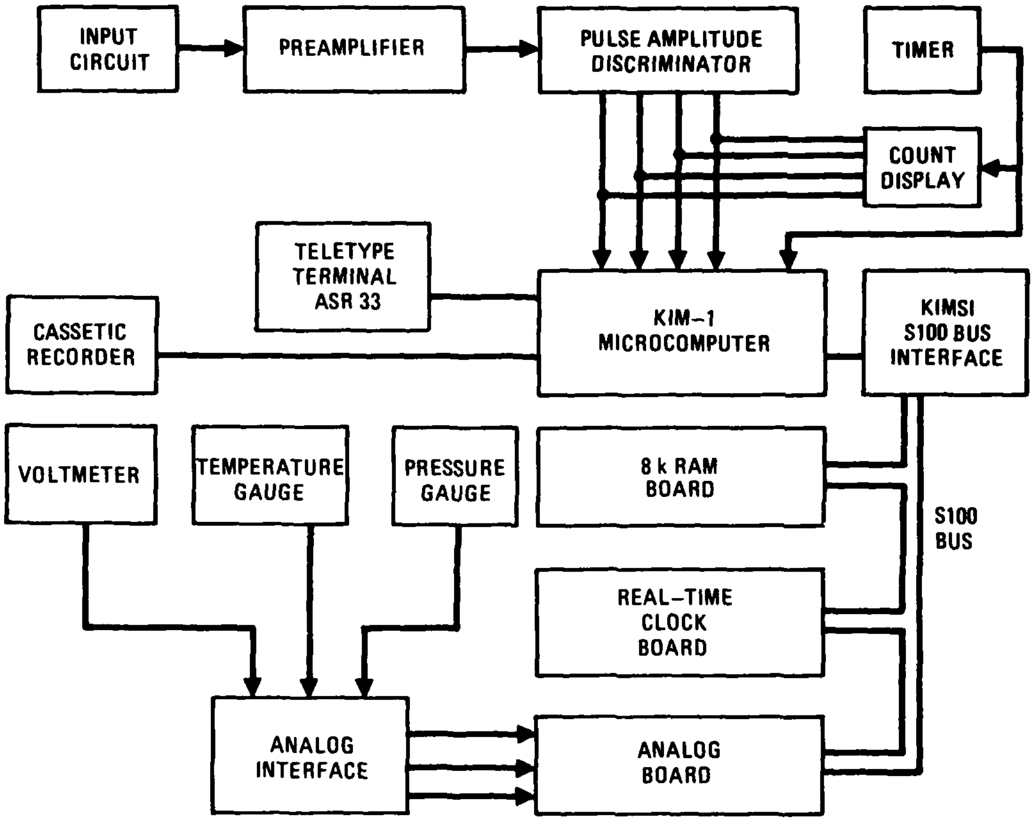


Fig. 4. Partial-Discharge Test System with KIM-1 Computer

C1	---	0-2000 pF	R1	---	10 k	L1	---	1 mH
C2, C4, C6, C8, C11, C13, C15, C17,	---	0.01 μFd	R2, R6, R9, R19, R20, R22	---	10 k	Q1	---	2N4381
C3, C5, C7, C10, C12	---	0.1 μF	R3, R7, R10, R13	---	100 k	Q2, Q3	---	2N2222
C9	---	2 μFd	R4, R8, R11, R14	---	10 k 10T POT	D1 THRU D8	---	FD 400
C14, C16	---	25 μF	R5	---	14 k	D9, D10	---	1N3807
C19	---	1.0 μF	R12, R23, R27	---	1 k	IC1	---	SN74121
			R15	---	390 k			
			R16	---	120 k			
			R17	---	1.4 M			
			R18, R21, R26	---	1.0 M			
			R24	---	500			
			R25	---	5 k			
			R28	---	39 k			
			R29	---	300			

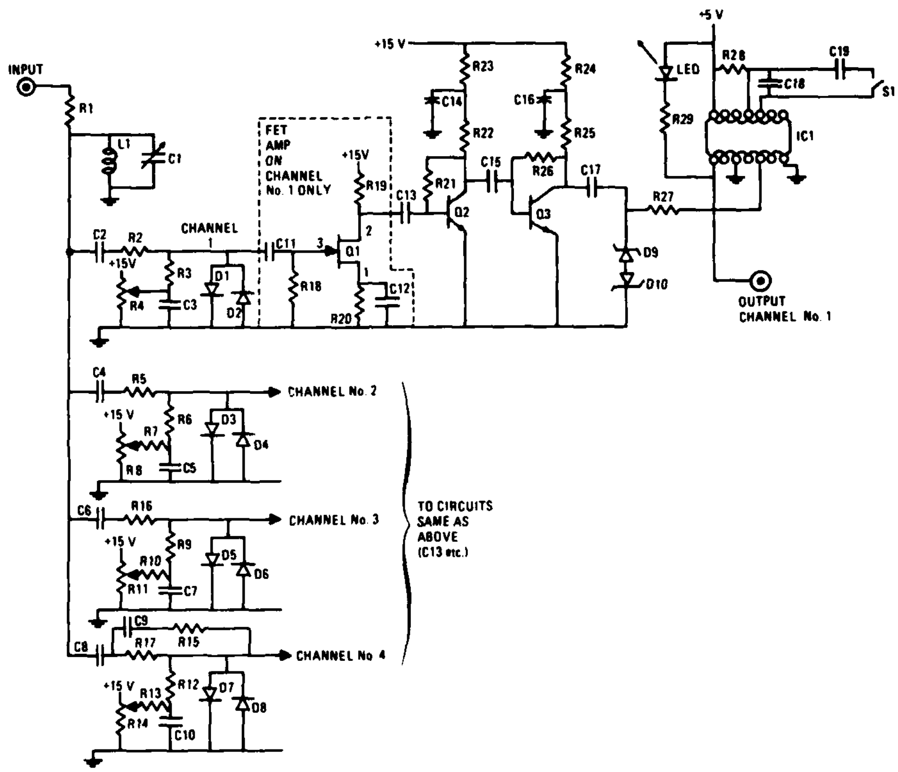


Fig. 5. Pulse Amplitude Discriminator

used to monitor counts in real time. The microcomputer also calculates the difference in total counts between channels, resulting in four pulse amplitude groups. For example, if the four discriminator thresholds are 0.25, 2.5, 25, and 250 pC, the groups are 0.25-2.5, 2.5-25, 25-250, and >250 pC. The groups can be shifted to higher levels by means of the preamplifier gain control. For example, if the gain is × 0.001, the above groups would be in units of nanocoulombs instead of picocoulombs.

Counting and subtraction takes place in software in the KIM-1 6502 machine language. The four pulse-height groups are displayed on a teletype terminal along with a printout of time, temperature, voltage, and pressure.

Peripherals were added to the KIM-1 microcomputer by means of the S-100 bus and KIMSI interface manufactured by Forethought Products. The peripherals consisted of the following three S-100 boards:

1. 8K RAM (Godbout "Econoram")
2. Real-time clock (Canada Systems CL2400)
3. Analog board (Vector Graphics Analog-1)

(The real-time clock board required modification before it could be used with the KIMSI interface. The connections to address bus pins A8 through A15 had to be rewired to pins A0 to A7 by cutting the stripes and using jumper wires on the board.)

An analog interface (Fig. 6) was used to interface the temperature, voltage, and pressure signals to the analog board. Analog-to-digital conversion was implemented in the microcomputer software as part of the printout routines.

All software was saved and loaded by means of a cassette recorder and standard audio cassettes.

The laboratory installation of the KIM-1 system is shown in Figs. 7 and 8. The teletype terminal is a model ASR 33 and includes a paper tape punch. The paper tape can be used to transfer data to a data conversion facility for

IC1, IC2, IC3	A 741	R5, R12, R19, R21	10k	R16	33k
R1, R7, R17	10 k TRIM-POT	R6, R13, R22	4.3 k	R18	15k
R2	680 k	R8, R9	1 M	R20	1.2 M
R3, R11, R14	1 M TRIM-POT	R10	470 k	R22	4.3 k
R4	270 k	R15	22 M		

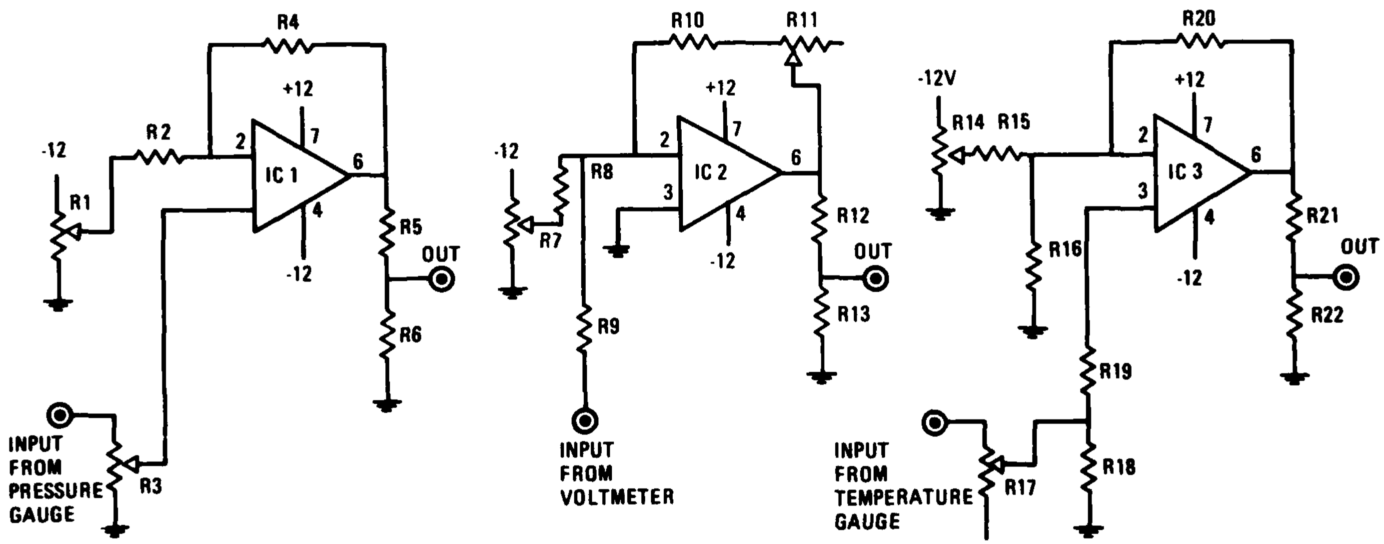


Fig. 6. Analog Interface

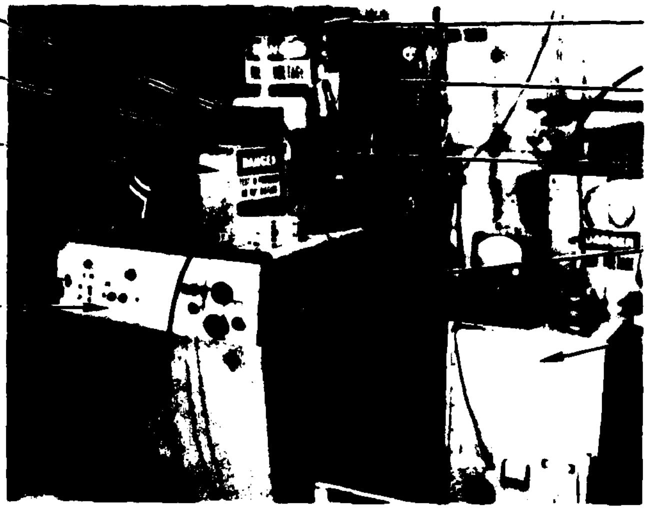


Fig. 7. Partial-Discharge Test System

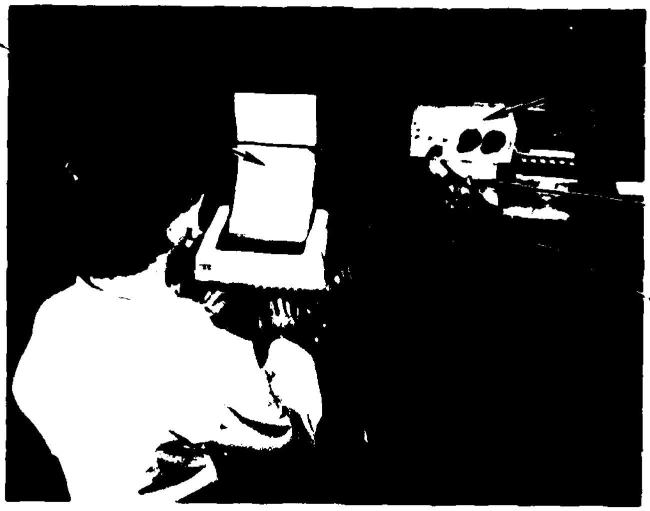


Fig. 8. Automated Data Collection, KIM-1 System

output in graph form.* Figure 9 is a sample of the teletype output. It takes approximately 7 sec for the teletype to print one line of data. The system does not count discharges that occur during that interval.

The values printed for vacuum pressure are output voltages from the vacuum gauge (Granville-Phillips catalog No. 275096). A graph of pressure versus voltage is supplied by the manufacturer.

B. HEWLETT-PACKARD SYSTEM

Figure 10 is a block diagram of the second test system. The input circuit and preamplifier are as previously described. A tunable filter, such as R1-L1-C1 (Fig. 5), can also be used after the preamplifier to increase the signal-to-noise ratio. This system utilizes the Hewlett-Packard 9835A desktop computer with the HP-IB(IEEE 488) bus interface. Operation is similar to that of the KIM-1 system (Fig. 4) except that counting of partial-discharge pulses is performed by four counters (HP 5328A), which can also be programmed as analog-to-digital converters. Each counter is preceded by a separate amplifier (HP 465A) and voltage limiter (R1-R4, D1-D8). The pulse amplitude thresholds are set by means of threshold adjustments on the counters. A 0.5-msec dead time is used to prevent multiple counting of single discharges. The digital outputs of the counters are processed by the computer through the HP-IB bus interface (HP 98034A).

As with the KIM-1 system, the difference in total counts between channels is calculated by the computer so that the results can be displayed as four-pulse-amplitude groups.

The real-time clock (HP 98035A) serves two purposes. It provides the month, day, hours, minutes, and seconds for printout with the other data and also provides the time base for the counting period. The time-base interval is programmed in the computer software and utilizes the interupt capability of the computer. The analog signals for temperature, voltage, and pressure are

*C. E. Mack, Data Conversion Process, personal communication, The Aerospace Corporation, El Segundo, Calif. (9 July 1980).

Ch. 2	Ch. 3	Ch. 4	Ch. 5	Time	Temp.	Voltage	Pressure
001369	019325	000000	000000	23:42:25	61C	5200V	0000MV
002166	024598	000001	000000	23:59:05	65C	5200V	0000MV
003922	039537	000000	000000	00:15:45	68C	5200V	0000MV
007100	051815	000000	000000	00:32:25	71C	5200V	0000MV
008298	056465	000000	000000	00:49:05	73C	5200V	0000MV
008792	056455	000004	000000	01:05:45	75C	5200V	0000MV
009955	055187	000122	000000	01:22:25	77C	5200V	0000MV
010888	059181	000397	000000	01:39:05	78C	5200V	0000MV
011208	058352	001921	000000	01:55:45	79C	5200V	0000MV
010343	060522	002895	000000	02:12:25	79C	5200V	0000MV
008799	053351	005784	000000	02:29:05	80C	5300V	0000MV
007445	049983	007967	000000	02:45:45	80C	5200V	0000MV
006794	043705	010275	000000	03:02:25	74C	5300V	0000MV
005597	001545	000195	000000	03:19:05	59C	5300V	0000MV
002135	010390	000081	000000	03:35:45	44C	5300V	0000MV
000463	006875	000001	000000	03:52:25	31C	5300V	0000MV
001779	001469	000003	000000	04:09:05	19C	5300V	0000MV
000045	000220	000001	000000	04:25:45	08C	5300V	0000MV
000000	000000	000000	000000	04:42:25	01C	5300V	0000MV
000000	000000	000000	000000	04:59:05	-04C	5300V	0000MV
000004	000000	000000	000000	05:15:45	-07C	5300V	0000MV
000001	000000	000000	000000	05:32:25	-04C	5300V	0000MV
000000	000000	000000	000000	05:49:05	06C	5300V	0000MV
000000	000000	000000	000000	06:05:45	17C	5300V	0000MV
000006	000000	000000	000000	06:22:25	26C	5300V	0000MV
000498	000312	000000	000000	06:39:05	34C	5300V	0000MV
000136	001557	000002	000000	06:55:45	41C	5300V	0000MV
006021	004238	000007	000000	07:12:25	46C	5300V	0000MV
001431	005621	000110	000000	07:29:05	50C	5300V	0000MV
001915	016140	000000	000000	07:45:45	54C	5300V	0000MV
001252	016845	000000	000000	08:02:25	57C	5300V	0000MV
001412	018993	000000	000000	08:19:05	59C	5300V	0000MV
001723	021798	000004	000000	08:35:45	61C	5300V	0000MV
002197	025566	000012	000000	08:52:25	63C	5300V	0000MV
002871	032251	000001	000000	09:09:05	66C	5300V	0000MV
008914	041001	000000	000000	09:25:45	68C	5300V	0000MV
017272	044987	000000	000000	09:42:25	70C	5300V	0000MV
026952	051242	000002	000000	09:59:05	72C	5300V	0000MV
016322	059306	000001	000000	10:15:45	74C	5300V	0000MV
010905	061190	000000	000000	10:32:25	75C	5300V	0000MV
011945	069162	000003	000000	10:49:05	76C	5300V	0000MV
012756	068004	000000	000000	11:05:45	66C	5300V	0000MV
005923	036326	000001	000000	11:22:25	51C	5300V	0000MV
001243	010995	000026	000000	11:39:05	37C	5200V	0000MV
000977	004552	000004	000000	11:55:45	25C	5200V	0000MV
000701	000685	000001	000000	12:12:25	14C	5200V	0000MV
000006	000054	000000	000000	12:29:05	04C	5200V	0000MV
000001	000000	000000	000000	12:45:45	-02C	5200V	0000MV
000000	000000	000000	000000	13:02:25	-06C	5200V	0000MV

Fig. 9. Sample Output, KIM-1 System

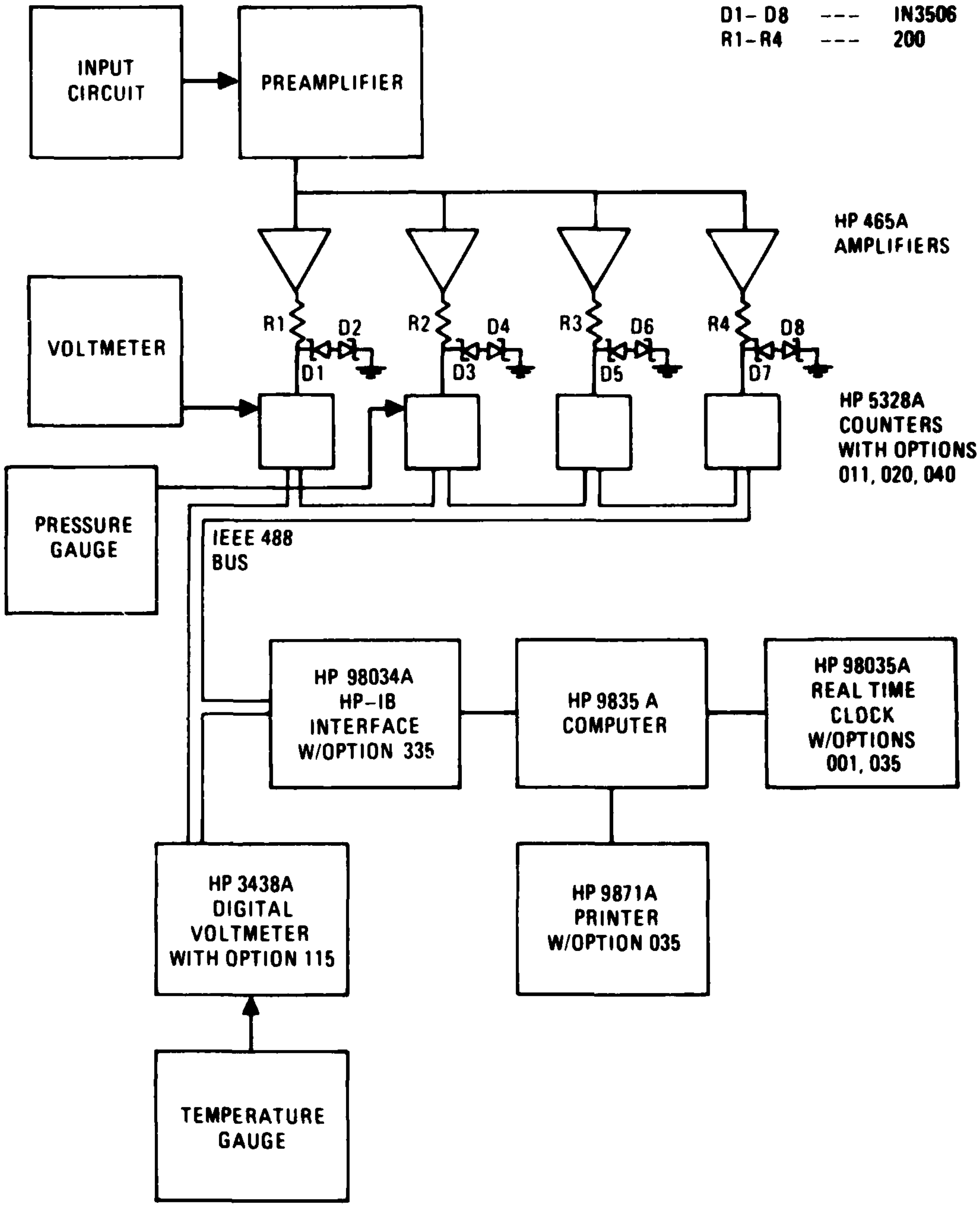
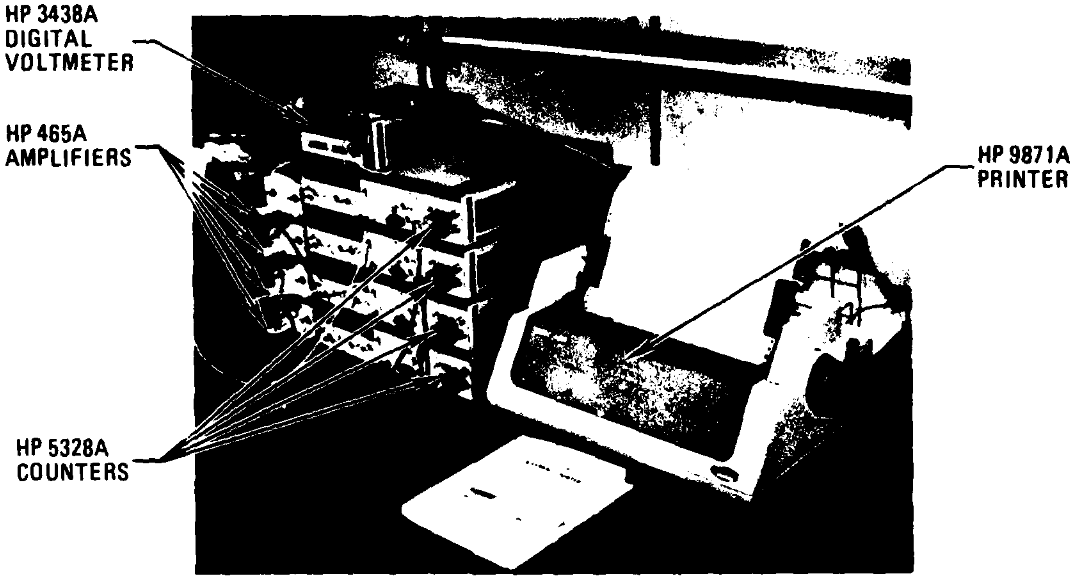


Fig. 10. Partial-Discharge Test System with Hewlett Packard Computer

also printed out under software control. For voltage and pressure, the HP 5328A counters are reconfigured as analog-to-digital converters by the computer program. A separate voltmeter (HP 5328A) was used for temperature readout because a lower analog voltage (1 mV/deg) was available from the temperature gauge. One of the HP 5328A counters could have been used instead if a dc amplifier was added.

The data consisting of the four count values and time, voltage, pressure, and temperature are printed out on the HP 9871A printer. This is a daisy wheel type printer, which can also function as a plotter. The computer program (Appendix A) controls the acquisition of data, processes it, prints it, and then, after a predetermined number of measurements, plots the data in the form of a graph. This cycle is repeated indefinitely until manually terminated. Plotting occurs simultaneously during the next acquisition cycle.

This system is superior to system 1 because it can easily be modified or expanded. Programs can be changed easily in the high-level language (BASIC), and instrumentation can easily be added to the IEEE 488 bus. Additional channels can be added by adding more counters. A single computer could be programmed to process data from several samples if additional input circuits, amplifiers, and counters were used. The system is shown in Fig. 11. Figure 12 is a sample of the printer output.



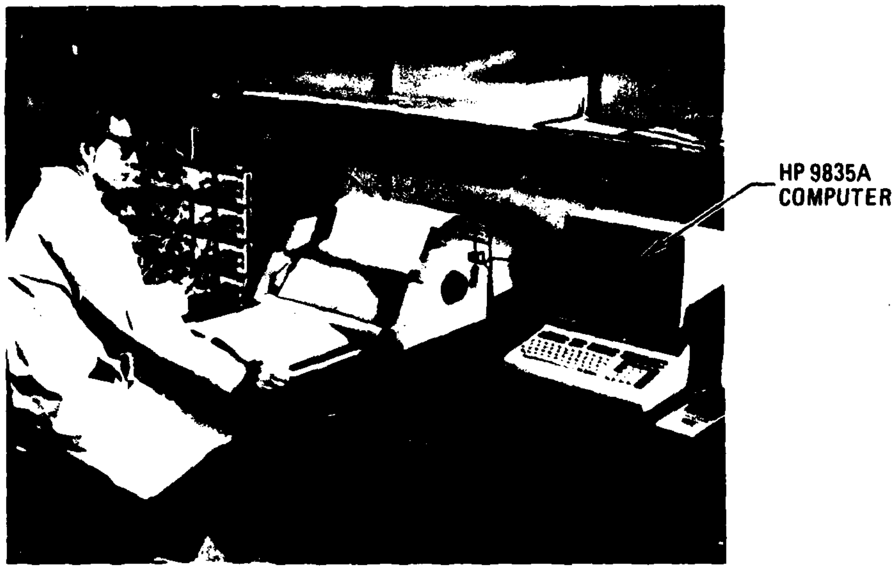


Fig. 11. Two Views of Automated Data Collection, Hewlett-Packard System

08:06:06:42:14

TIME	GROUP #1	GROUP #2	GROUP #3	GROUP #4	KILOVOLTS	PRESSURE	TEMP F	TEMP C
06:42:14	0	0	0	0	-3.0	.0	106.2	41.2
06:58:54	0	0	0	0	-3.0	.0	120.3	49.1
07:15:34	6	2	1	0	-3.0	.0	132.4	55.8
07:32:14	12	12	4	0	-3.0	.0	142.9	61.6
07:48:54	67	64	0	0	-3.0	.0	152.0	66.7
08:05:34	414	40	0	0	-3.0	.0	159.9	71.1
08:22:14	685	3	0	0	-3.0	.0	167.8	75.4
08:38:54	551	0	0	0	-3.0	.0	174.9	79.4
08:55:34	77	0	0	0	-3.0	.0	181.2	82.9
09:12:14	0	0	0	0	-3.0	.0	186.4	85.8
09:28:54	0	0	0	0	-3.0	.0	189.5	87.5
09:45:34	3	0	0	0	-3.0	.0	189.7	87.6
10:02:14	1	0	0	0	-3.0	.0	189.6	87.6
10:18:54	1	0	0	0	-3.0	.0	189.6	87.6
10:35:34	2	0	0	0	-3.0	.0	189.7	87.6
10:52:14	0	0	0	0	-3.0	.0	189.5	87.5
11:08:54	0	0	0	0	-3.0	.0	189.3	87.4
11:25:34	1	0	0	0	-3.0	.0	147.8	64.3
11:42:14	546	11	0	0	-3.0	.0	112.3	44.6
11:58:54	14	24	3	0	-3.0	.0	84.0	28.9
12:15:34	9	0	2	0	-3.0	.0	61.2	16.2
12:32:14	1	0	1	0	-3.0	.0	42.3	5.7
12:48:54	2	0	0	0	-3.0	.0	29.2	-1.6
13:05:34	1	0	0	0	-3.0	.0	20.6	-6.3
13:22:14	2	0	0	0	-3.0	.0	15.1	-9.4

System Gain - GX0.1

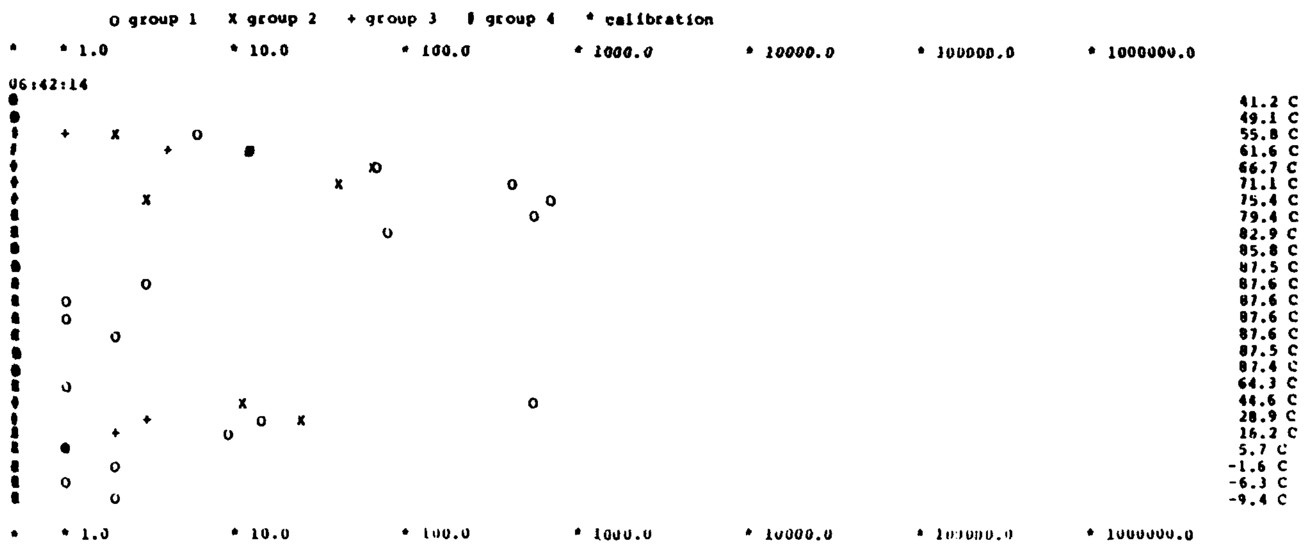


Fig. 12. Sample Output, Hewlett-Packard System

IV. TEMPERATURE CYCLING

The partial-discharge test systems, used at Aerospace, include a means for cycling the temperature of the test sample within the vacuum chamber. The sample is mounted on a copper plate with 1/2-in. copper tubing soldered to one side. The temperature of the copper plate is controlled by circulating a temperature-controlled fluid through the tubing. The sample is electrically isolated from the copper plate by a 1/8-in. slab of Mycalex sandwiched between the sample and the plate. The fluid, usually a Prestone II-water solution, is circulated and temperature controlled by means of a laboratory heater-circulator (Polyscience model 73) and refrigeration unit (Polyscience model KR60). The heater-circulator was modified to permit the heater to be deactivated when the refrigeration unit was turned on. This was done simply by connecting normally open relay contacts across the thermoregulator terminals. The relay coil (115 Vac) was connected in parallel with the refrigeration unit power input, which was connected to a 24-hr clock timer with adjustable "on" and "off" periods. The upper temperature limit is set by the thermoregulator, while the lower temperature limit is determined by the "on" time for the refrigeration unit. A copper plate temperature of about -10°C was achieved with a 70% Prestone II solution in water and a 2-1/2 hr "on" time, with a high temperature limit of 90°C.

V. DISCUSSION

Two methods were described for automating the readout of a partial-discharge test system. The main advantage of the KIM-1 system is low cost. Compared to the Hewlett-Packard system, it lacks versatility because the computer must count each individual partial-discharge pulse by means of its software routine. The program is difficult to modify because it is in machine language. The Hewlett-Packard system includes separate counters to count the partial discharges and can easily be modified by adding more instruments to the IEEE 488 bus system. For example, a programmable power supply could be added to automatically program the high voltage to the sample under test. Unlike the KIM-1 system, the Hewlett-Packard system allows discharges to be counted even during printout of the data for the previous counting period.

APPENDIX· BASIC PROGRAM LISTING FOR THE HEWLETT-PACKARD SYSTEM

```
5 ! Program for printing and graphing partial discharge data.  7/23/80
6 ! Uses arrays G$(N) & G(N,I) to store data for plotting.
10 Counter=0
12   INPUT "PLOT HOW MANY LINES PER GRAPH?",Lines
13   IF Lines>100 THEN 12
14   DIM G$(101)
15   DIM G(101,5)
20   OUTPUT 6;"Partial Discharge Testing"
30  ON INT #9 GOSUB Irq    ! Establish service routine
40  CONTROL MASK 9;128
50  CARD ENABLE 9        !Enable interupts
60  OUTPUT 9;"Unit2Halt,Unit2=Output2,Unit2Period 1000.000sec/Unit2Go"
70 OUTPUT 701,702,703,704;"PF1G0S1346=>UT"
80  PRINT "PROGRAM IN PROGRESS."
90  PRINT USING "#,K";CHR$(27)&"&a-1R"
100 Delay=630
110 GOSUB Delay
111  PRINT "    IN LOOP.         "
112  PRINT USING "#,K";CHR$(27)&"&a-1R"
113  GOSUB Delay
120 GOTO 80
130 END
140 Irq: OUTPUT 9;"T"      !Request trigger code
150 Source=READBIN(9)       !Read trigger code
160 CARD ENABLE 9           !Reenable interupts
170  GOSUB Measure
180  RETURN
190 Measure:  OUTPUT 9;"R"   !Read time
200  ENTER 9;T$
210 Time$=T$[7]             !Start with 7th character of T$
220 PRINT USING "#,K";CHR$(27)&"&a+2R"    !Moves curser up 2 rows (p. 242)
230  PRINT T$
240  IF Counter=0 THEN GOSUB 680
250  Counter=Counter+1
260  PRINT "Counter=";Counter
270 TRIGGER 723             !Voltmeter
280  ENTER 723;V$
290  PRINT V$
300 SENDBUS 723;"Untalk"
310 LOCAL 723
320 Temp=VAL(V$)*1000
330 Ctemp=(Temp-32)*5/9
340 Pc$="Deg. C"
350 PRINT "Temp.=";Temp;"Deg. F";"  ";Ctemp;Pc$
360 Pt$="Time="
370 Ptemp$="Temp="
380 Pf$="Deg. F"
390 FIXED 1
410 OUTPUT 701,702,703,704;"F0G0S5"   !Stop counting
420 ENTER 701;C1$                         !Read scaler
430  ENTER 702;C2$
440  ENTER 703;C3$
450  ENTER 704;C4$
460 PRINT C1$;C2$;C3$;C4$
470 OUTPUT 701,702,703,704;"PF7G4S0246:<>UT"          !Reconfigure as DVM
480 ENTER 701;Dvm1$                      !Read DVM
490  ENTER 702;Dvm2$
500  ENTER 703;Dvm3$
510  ENTER 704;Dvm4$
520 PRINT Dvm1$;Dvm2$;Dvm3$;Dvm4$
530 OUTPUT 701,702,703,704;"PF1G0S1346=>UT"          !Reconfigure as scaler
540 C1=VAL(C1$)
```

```
550  C2=VAL(C2$)
560  C3=VAL(C3$)
570  C4=VAL(C4$)
580  C1=C1-C2
590  C2=C2-C3
600  C3=C3-C4   !Calculate group counts by subtracting adjacent channels
610 V1=VAL(Dvm1$)
615 V1=V1*1.05
620 V2=VAL(Dvm2$)
630 V3=VAL(Dvm3$)
640 V4=VAL(Dvm4$)
650 IMAGE 8A,2X,8D,2X,8D,2X,8D,2X,8D,12X,MDDDDD.D,2X,MDDDDD.D,2X,MDDDDD.D,2X,MDD
DDD.D,6X,MDDD.D,2X,MDDD.D
660 OUTPUT 6 USING 650;Time$;C1;C2;C3;C4;V1;V2;Temp;Ctemp
661  N=Counter
662  G$(N)=Time$
663  G(N,1)=C1
664  G(N,2)=C2
665  G(N,3)=C3
666  G(N,4)=C4
667  G(N,5)=Ctemp
668 IF N>=Lines THEN GOTO 2800
670 RETURN
680 OUTPUT 6;RPT$("*",132)
690  OUTPUT 6;T$
700 IMAGE +, 8A,2X,8A,2X,8A,2X,8A,2X,8A,11X,9A,2X,8A,2X,8A,2X,8A
710  OUTPUT 6 USING 700;"  TIME","GROUP #1","GROUP #2","GROUP #3","GROUP #4","KI
LOVOLTS","PRESSURE","  TEMP F","  TEMP C"
720 OUTPUT 6;"________  ________  ________  ________  ________         ________
  ________  ________"
730 OUTPUT 6;" "
750 RETURN
760 Delay:I=0
770 I=I+1
780 IF I=Delay THEN RETURN
790  GOTO 770
800  END
1000 FOR N=1 TO Lines
1001 Time$=G$(N)
1002 C1=G(N,1)
1003 C2=G(N,2)
1004 C3=G(N,3)
1005 C4=G(N,4)
1006 Ctemp=G(N,5)
1015 IF N=1 THEN OUTPUT 6;Time$
1020 X=C1
1030 Point$="O"
1040 GOSUB Plot
1050 GOSUB Rlf  ! Reverse linefeed
1060 X=C2
1070 Point$="X"  ! Group 2
1080 GOSUB Plot
1090 GOSUB Rlf
1100 X=C3
1110 Point$="+"   ! Group 3
1120 GOSUB Plot
1130 GOSUB Rlf
1140 X=C4
1150 Point$="#"   ! Group 4
1160 GOSUB Plot
1170 GOSUB Rlf
1180 OUTPUT 6;RPT$(" ",123);Ctemp;"C"
1190 NEXT N
1200 RETURN
2140 Cal:  ! Subroutine for calibration points
2150 DIM Y$[200]
```

APPENDIX: BASIC PROGRAM LISTING FOR THE HEWLETT-PACKARD SYSTEM (Continued)

```
2160 INTEGER Y
2170 Point$="*"
2180 X=0
2190 Cal=1
2200 GOSUB Plot
2210 GOSUB Rlf
2220 FOR E=0 TO 6
2230   X=10^E
2240   GOSUB Plot
2250   GOSUB Rlf
2260 NEXT E
2270 GOSUB Lf
2280 Cal=0
2290 RETURN
2300 Plot:  ! Subroutine for plotting points
2310 IF X<1 THEN GOTO 2440
2320 Y=90*LOG(X)
2330 IF Y<1 THEN Y=1
2340 OUTPUT 6;"     ";
2341 OUTPUT 6 USING "#,B";27,82,INT(Y/64),INT(Y),0,0
2350 IF Cal>0 THEN GOSUB 2460
2360 IF Cal=0 THEN GOSUB 2480
2370 RETURN
2380 Lf:OUTPUT 6 USING "#,B";10   !Linefeed
2390 RETURN
2400 Rlf:OUTPUT 6 USING "#,B";27,10  ! Reverse linefeed
2410 RETURN
2420 Cr:OUTPUT 6 USING "#,B";13    ! Carriage return
2430 RETURN
2440 OUTPUT 6;Point$   !Zero point
2450 RETURN
2460 OUTPUT 6;Point$;X    ! For calibration
2470 RETURN
2480 OUTPUT 6;Point$      ! For plotting
2490 RETURN
2800 GOSUB Lf
2810 OUTPUT 6;RPT$("-",132)
3000 OUTPUT 6;"          O group 1   X group 2   + group 3   # group 4   * calib
ration"
3002 GOSUB Lf
3010 GOSUB Cal
3020 GOSUB Lf
3025 GOSUB 1000
3028 GOSUB Lf
3030 GOSUB Cal
3040 GOSUB Lf
3050 Counter=0
3080 RETURN
```

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the Nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Aerodynamics; fluid dynamics; plasmadynamics; chemical kinetics; engineering mechanics; flight dynamics; heat transfer; high-power gas lasers, continuous and pulsed, IR, visible, UV; laser physics; laser resonator optics; laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric reactions and optical backgrounds; radiative transfer and atmospheric transmission; thermal and state-specific reaction rates in rocket plumes; chemical thermodynamics and propulsion chemistry; laser isotope separation; chemistry and physics of particles; space environmental and contamination effects on spacecraft materials; lubrication; surface chemistry of insulators and conductors; cathode materials; sensor materials and sensor optics; applied laser spectroscopy; atomic frequency standards; pollution and toxic materials monitoring.

Electronics Research Laboratory: Electromagnetic theory and propagation phenomena; microwave and semiconductor devices and integrated circuits; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, superconducting and electronic device physics; millimeter-wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; composite materials; graphite and ceramics; polymeric materials; weapons effects and hardened materials; materials for electronic devices; dimensionally stable materials; chemical and structural analyses; stress corrosion; fatigue of metals.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.